Advances the in Utilization of Bamboo for Paper Production and the Implication for Countries with Bamboo Resources

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Abstract
The fibrous raw materials for pulp and paper production have expanded considerably since paper was discovered in China in 105 AD. Today, apart from hemp, rags and the bark of mulberry tree that were used during this period, many wood and non-wood fibres including agricultural residues are used for pulp and paper production. While wood continue as a major fibrous raw material for paper production, bamboo utilization for pulp and production is also expanding. While bamboo has challenges such as silica deposition, it also has a number of advantages that are promoting its utilization in the pulp and paper industries. Among the advantages of bamboo include its high fibre length compared with hardwoods and other non-wood fibres, high growth rate and generation good chemical composition. This is gradually leading to expansion in bamboo pulp and paper production globally. Counties with adequate bamboo resources could take the advantages inherent in bamboo production and pulping to develop their pulp and paper industries.

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1.Introduction

The fibrous raw materials for papermaking have expanded considerably since AD 105 when paper was discovered in China. From using hemp, rags and bark of mulberry tree, the fibrous raw materials used and the pulping processes have advanced considerably. Today, three major pulping processes have been developed with more than twenty variants that can be used at small, medium and large scale levels. Likewise, fibrous raw materials have expanded from the domain of rags to other non-wood plants and subsequently, wood. For a long time, wood has become the principal fibrous raw material for pulp and paper production due to its ubiquity, high pulp yield, adaptation to major pulping processes, ease of transportation and long storage periods. Pulping of wood also provides an economic use for slabs, edgings, and other forms of wood waste in large integrated wood conversion operations. Likewise, the development of mechanized pulpwood harvesting and field chipping has also accelerated the use of chips for both pulp and as hog fuel. Consequently, today, pulpwood ranks amongst the most important commodities in world trade, after oil and food.

Despite the above, several factors are also facilitating increasing adoption of non-wood fibres in pulp and paper making. Among these are scarcity of wood in many countries, sustainable availability of non-wood fibrous raw materials at little or no cost to the mills and the increasing the demand of pulp and paper. The use of non-wood plants in countries with unsustainable wood resources, offers the economic advantage of producing paper with available resources, thereby saving foreign exchange and promoting a growing domestic market for paper output (Ogunwusi, 2014a). Due to this, many non-wood fibrous raw materials are currently being used for pulp and paper production. Among these are agricultural residues such as bagasse, straw, hemp, jute, abaca, reed, kenaf and bamboo.

Out of all these, bamboo is regarded as the most economic and emerging resource for worldwide pulping and papermaking (Chen *et. al*., 2019). Among the reasons for these are wide distribution in subtropical and tropical areas, most especially in Asia Pacific Region, the Americas Region, and Africa (Mera and Xu, 2014). It is widely present in many developing regions that lack wood resources. Bamboo has the advantages of a short rotation cycle (3-5years), natural regeneration and low maintenance cost. As a fast growing species, bamboo contains 57 to 66wt% cellulose, 27 to 30 wt% hemicellulose and 4 .9 to 5 wt% lignin (Wei et al. 2016) . Considering its chemical composition, bamboo is a better fibre raw material for pulp and papermaking compared with other non-wood fibres. Other advantages of bamboo over other non-wood fibres for papermaking include high productivity as it grows up to 120 cm per day making its productivity 2-6 times higher than pine plants and an average fibre length of about 1980 μm which is higher than most other non-wood fibres except cotton and cotton linters (Ogunwusi, 2014b). These attributes have made the pulping characteristics of bamboo to be subjected to intensive research and development globally. This paper reviews the advances that have been made in bamboo pulp and paper production in countries with adequate bamboo resources, but depends on pulp and paper importation, there limiting the growth of their pulp and paper sector. Most of these countries expend a lot of foreign exchange pulp and paper importation to the detriment of the development of local industries.

2. The Challenges of Bamboo Pulp and Paper Production

In 2010, all pulp and paper mills produced 146 million tonnes of pulp which includes 2 million tonnes of bamboo pulp. The proportion of bamboo used in paper production was not very high due to certain limitations. One of the major reasons is that bamboo does not grow in all regions of the world. It grows well in warm and humid areas, most especially in the tropics and in Southeast Asia. Available statistics have shown that India, Bangladesh, Thailand and China are the world's largest countries using bamboo pulp for paper pulp making. For instance, India produces an annual output of 1,360,000 tons bamboo pulp for paper pulp making, the Indo-China Peninsula (including Thailand, Vietnam, Kampuchea, Burma) 900,000 tons while China produces 600,000 tons**.** However, bamboo utilization is increasing in China and India. In China, the need to expand pulp and paper capacities due to increasing demand is leading to increase in bamboo utilization despite the increasing expansion in pulpwood plantation development in the country.

Secondly, the black liquor is difficult to recover. As a result, in places where water bodies are limited, there may be problems for the development of bamboo pulp and papermaking industries. Bamboo has relatively higher ash and silicon contents compared with wood materials (Sharma *et al*. 2011, Ogunwusi, 2013). This can negatively impact the recovery process for alkaline spent liquor and the quality of some high-grade pulp products such as dissolved pulp. This development has militated against the use of bamboo in some parts of the world. In the tropics, most especially in sub Saharan Africa, the problems are complicated by the technical considerations concerning plantation development, low level of investment and general underdevelopment of the pulp and paper sector as a result of non incentivization of the initiative by policy makers. While countries in South East Asia, most especially, China and India are expanding pulp and paper capacities through introduction of various incentives such as pioneer status, release of permit to new investors and constant upgrading of activities in the sector in order to promote increase use of bamboo, most governments in Sub-Sahara Africa encourages importation rather than development of local industries based on locally available raw materials. These have made most countries in Sub Sahara Africa to depend almost entirely on pulp and paper importation. Third, when bamboo chips are cooked, air is trapped inside the bamboo ducts. This hinders the penetration of the liquid. Sand mixed with silt and gravel is difficult to remove by screening, leading to high rate of equipment wear and tear and lowered pulp quality.

According to Zhang (2019), there are other challenges of confronting bamboo pulping and papermaking. However, some of the problems have to do with bamboo plantation establishment and logging, storage and transportation of the materials. With respect to raw material supply, bamboo has a higher cost of logging, storage, and transportation compared with wood raw material. Moreover, due to the uniqueness of bamboo chips and their supply/ transportation issues, the production scale of bamboo pulping mills is usually smaller than that of wood pulp mills. The price of bamboo chips is also frequently influenced by the market fluctuations. The fiber raw material cost for bamboo pulp can be as high as 60% of the total production cost (Wu 2016). To address this issue and ensure a stable supply of bamboo chips, pulp mills can establish their own bamboo plantations and sign long term contracts with local bamboo farmers (Zhang, 2019).

3. The Prospects of Bamboo Pulping

The development potential of bamboo pulp papermaking in developing countries such as Nigeria is high. For instance in Nigeria, bamboo grows extensively in the South West, South East, South South and North Central vegetation zones of the country. Bamboo was extensively used in Nigeria by the Nigeria Paper Mill, Jebba in the North Central part of the country before it closed operations in 1996. Mixed with imported long fibre pulp, bamboo was extensively used to produce kraft paper for production of packaging materials. However, since the mill was privatized in 2006 and put into operation, it has not been used to produce primary pulp.

Various studies have shown that the performance of bamboo pulp lies between softwood pulp and hardwood pulp. It is obviously better than straw pulp. It can be used to produce culture paper, living paper and packaging paper. As a result of its characteristics of fast growth, short cycle, renewable and sustainability, high quality and high yielding bamboo can be produced for integrated bamboo pulp and paper production.

Bamboo is the best grade of non-wood resource for paper making in view of morphology, high content cellulose fiber, thin and solid fiber and good plasticity. Its fiber length lies between hardwood and softwood. With the development of continuous cooking and non-chlorine pollution-free bleaching methods, the problems of bamboo pulp and paper quality is gradually abating. The pulp can be used alone or matched with wood pulp or straw pulp in appropriate proportions to produce high quality culture paper, living paper and packaging paper.

The annual yield of bamboo can reach 3-4 tons per hectare. 1 ton of paper needs about 4 tons of fresh bamboo. Experts' investigation has shown that a mill with an annual production capacity of 50,000 tons of bamboo pulp, the profits after taxes on each ton of paper is more than 35% depending on country and locality. Among the advantages of bamboo is that unbleached paper can be made from pure natural plant fiber extracted from bamboo pulp, bagasse pulp as straw pulp for raw materials. If Nigeria is to continue with the adaptation trials that was done in the 1960's-1970 on *Pinus caribaea* and *Pinus oocarpa*, it may take more than 15 years before sustainability of supply can be achieved. Thus, gregarious development of bamboo and establishment of facilities for pulp and paper production from it is the best option for Nigeria and most developing countries in the Sub Saharan region of Africa in the short to medium term.

4. Advances in Pulp and Paper Production from Bamboo

According to Chen Lihui, papermaking from bamboo began in the Jin Dynasty. The development of bamboo pulp and papermaking was gradual. The technology of papermaking from bamboo was not popular in Europe until the 19th century. At first, bamboo fibres could not be divided into fibrils. As a result, the papers produced were rough. However with the advancement in technology, paper produced from bamboo pulp has become acceptable and widely utilized. Compared with wood, bamboo has a higher density. As a result, at the initiation of bamboo pulp and papermaking process, tender bamboo culms were usually used for pulping and papermaking due to the high density and high linin content of bamboo which leads to delignification problems. The low density and lignin contents of tender bamboos permit penetration of the cooking liquor and the removal of lignin. More recently however a number of advances and innovation have been made in pulping technology, which has made it possible to produce high quality pulp and paper products from bamboo of different ages using different pulping processes.

Dhamodaran et al (2003) provided a detailed review of advances that have been made overtime in bamboo pulping using various pulping processes. According to the review, investigations for utilizing bamboo for different types of pulps started in the early 1890s. *Bambusa bambos* and *Dendrocalamus strictus* were reported to be suitable for the production of rayon pulp (Karnik and Sen 1948). The preparation of dissolving pulp from bamboo was described by Jogleker and Donofrio (1951) while the use of *Phyllostachys bambusoides* of not more than 15 years of age as a raw material for the preparation of dissolving grade pulp by prehydrolysis and sulphate pulping was described by Nafziger *et al*. (1960). This species was also suggested for producing newsprint from chemical, semi-chemical and mechanical pulps.

Dissolving pulp from *Melocanna bambusoides* was prepared by prehydrolysis sulphate process (Oye and Mizuno 1970). From *Ochlandra travancorica,* viscose rayon grade pulp was prepared by prehydrolysis sulphate process (Bhat and Viramani 1961). Prehydrolysis cooking of bamboos at 160 – 165 ^{0} C for 4 hours followed by sulphate cooking at 160 ^{0} C for 2 hours with a total sodium hydroxide 20 per cent and sulphidity 20 per cent, were suggested for the preparation of dissolving grade pulp (Tsuji *et al*. 1965). With these prehydrolysis conditions, pentosans were less than 5 per cent. The average degree of polymerisation compared favourably with that of similar pulps from wood. In comparison with wood, bamboo pulp has a higher rate of depolymerisation during aging, low cold-alkali solubility but comparatively high hot-alkali solubility, and a similar degree of crystallinity, but a higher rate of acid hydrolysis and lower levelling of degree of polymerisation (Oye and Mizuno 1970). The chemical properties and filter abilities of viscose showed no great difference from those of wood.

High-yield and pulp high tear strength suitable for paper making was produced from *Bambusa vulgaris, B. vulgaris* var. *vittata* and *B. tuldoides,* in Southern Brazil by(Mazzei *et al*. (1967). One-year-old culms gave the best result. Escolano and Semana (1970) also reported the suitability of *Bambusa vulgaris* sulphate pulp for paper. On the basis of the quality of pulp, optimum conditions for producing kraft pulp from *Oxytenanthera ritcheyi* were described by Bhandari (1981). Tissot (1970), discussed the problem of making pulp and paper from bamboo on the basis of the study carried out in four Indian mills. The cooking processes used (kraft, sulphite and neutral sulphite) and the bleaching and refining procedures followed were reviewed and suggested solutions to overcome problems of blade wear due to the presence of silica.

Mechanical pulping

The mechanical pulping of bamboo was reported by Bhat and Viramani (1957). The study showed that the newsprint prepared from the furnish of groundwood pulp and chemical pulp in the ratio 70:30 was as strong as the then imported newsprint. Likewise, soda thermo-mechanical (STM) and soda sulphite thermo-mechanical (SSTM) pulp from bamboo (*Dendrocalamus strictus*) was prepared from pre-impregnated chips, using a 10 per cent solution of NaOH and a mixture of NaOH and sodium sulphite in the ratio of 4:1 separately, respectively. Mukherjea and Guha (1965) described a newly developed chemi-mechanical high-yield process used at FRI, Dehra Dun, India for pulping non-wood forest products including bamboos. The resultant pulps were reported to be suitable for preparing newsprint, writing, printing and grease-proof papers.

Cold-soda pulping

According to Dhamodaran *et al,* (2003), Gremler and McGovern (1960) reviewed the history of cold-soda pulping, emphasizing the various continuous methods used. Pulping *Bambusa polymorpha* showed that short impregnation periods would result in completely defibrated pulp with high freeness. Good quality hand-made paper was produced from the cold- soda bamboo pulp (Rao *et al*. 1962) 364. Later, Nicholas and Navarro (1964) evaluated the cold-soda pulps from some Philippine bamboos while the characteristics of unbleached bamboo cold-soda pulp were described by Islam *et al*. (1989). They observed that the sulphite process gave the best results and soda process the poorest for pulping bamboo. In a study reported by Devgan (1964), it was observed that the incorporation of 2 per cent elemental sulphur in the soda-cooking of *Dendrocalamus strictus* improved pulp and paper performances. The kinetics of alkaline pulping of *Dendrocalamus strictus* was described by Singh and Guha (1975). They observed that up to the yield level of 70 per cent, there was a linear correlation between the lignin content and kappa number as well as between lignin-carbohydrate ratio and yield.

Kraft pulping

In line with the Dhamodaran et al (2003) review, a kraft cooking conditions of 20-22 per cent alkali, 25 per cent sulphidity, 162-177 0C temperature and 5-6 hours cooking time for the pulping of culms of all ages in a mixture including nodes, were used to successfully pulped bamboo by Raitt (1912). A fractional method of digestion was developed later which involved 10 per cent total alkali on air-dry bamboos at a concentration of 2 per cent alkali for 2 hours at 115-121 0C for the first stage followed by a second stage consisting of a total alkali of 18 per cent on air-dry bamboo at a concentration of 6 per cent cooking liquor for 3 hours treatment at 150 0C. The spent liquor from the second stage of digestion was used for the first stage. The pre-cook could be considered as buffered soaking at high temperature, to achieve penetration without damage to the carbohydrates prior to the actual cooking reactions. Yield of 45-50 per cent unbleached pulps was obtained. The sulphate pulping of reed bamboo was reported to produce 92.7 per cent alpha-cellulose (Anonymous 1947). The requirements of alkali charges for the unbleached and bleached grades of bamboo pulp at temperatures of 160-170 0C for several hours were described by Anonymous (1949) and Sproull (1955). *Bambusa vulgaris* from Mexico was reported to be suitable for kraft pulping (Carrasco and Salvador 1961) 30. The giant Philippine bamboo *Gigantochloa aspera* was reported to produce sulphate pulps of excellent tearing strength (Monsalud 1964). By maintaining optimum conditions for sulphate cooking, it was possible to obtain good quality kraft pulp with a yield of 45 per cent from *Neohouzeaua dulooa* (Nepenin and Bang 1969). The kraft/sulphate pulps were darker and hard to bleach, but were strong enough for packaging products. Later, Kadarisman and Silitonga (1974) described the sulphate pulping of some South-East Asian bamboos. Sulphate pulping of *Dendrocalamus giganteus* was tried and results were compared with those of *D. strictus*, the main species of bamboo used for pulp and paper in India. The result showed that *D. giganteus* is a better raw material for both unbleached and bleached pulps (Guha *et al*. 1975). Unbleached pulp from *Bambusa tulda by* kraft process can be produced with a yield of up to 44.1 per cent and the result showed that the species is suitable for the manufacture of wrapping, writing and printing papers (Bhola 1976).

Kraft-anthraquinone (AQ) pulping

Low sulphidity (15%) kraft pulping of muli bamboo (*Melocanna baccifera*) with anthraquinone (0.05%) increased the pulp yield by 2 per cent of oven-dried bamboo compared with that from low sulphidity kraft pulping alone, and by 0.8 per cent over that of normal (25% sulphidity) kraft pulping (Maheshwari 1979; Nazak *et al*. 1979). The viscosity of AQ-catalysed low sulphidity kraft pulps was almost equal to that of the normal kraft control and better than that of the pulp from low sulphidity (15%) kraft pulping alone. Burst, tear and tensile strength properties were almost the same as or better than that of pulp obtained in normal kraft pulping. This makes the use of AQ beneficial at low sulphidity in improving the yield and quality of the pulp in addition to reduction of air pollution as a result of the lower sulphidity (Bhowmick *et al*. 1991; 1992). A tentative economic analysis of kraft and soda-anthraquinone pulping of muli bamboo showed that better benefits could be achieved in soda + AQ pulping compared with soda pulping (Goyal and Misra 1982; Bhowmick *et al*. 1992).

5. More research in bamboo pulping

Based on the advances made in the technology of pulp and paper production from bamboo, several successful bamboo pulp and paper mills have been established to pulp bamboo and some other non-wood plant species (Fahmy *et al,* 1970, 2017) . In recent years, intensified and assiduous research and development has continued to confirm the possible utilization for pulp and paper production using different pulping processes. Eraldo *et. al*. (2019) evaluated the technological characteristics of kraft pulp production from *Bambusa vulgaris*, *Eucalyptus species* and *Pinus species* in order to make complete comparison among the plant species. Results of the study indicated that B vulgaris has higher basic density, lower hollocellulose content and higher total extractive content. It fibres have intermediate length and cell wall thickness similar to the *Eucalyptus spp* and *Pinus spp*. The B. vulgaris was easier to delignify besides having no rejects and smaller consumption of active alkali. However, the Eucalyptus species and the *Pinus species* have higher yields, the lowest specific consumption of of raw materials and better selectivities. Also in a study on kraft and modified kraft pulping of *Phylostachys bambusoides* grown in the Eastern Black sea region of Turkey using kraft, kraft anthraquinone (AQ) and kraft sodium borohydride (NA_2BH_4) pulping processes under a variety of conditions to determine the effects of AQ,

NA_2BH_4 and cooking parameters Deniz *et. al*. (2017) observed the modified kraft method with 0.1% AQ to provide better pulping properties than those with 0.30% NA_2BH_4. Increasing the thickness of chips from 2.0mm to 4.0mm increased the yield. The yield from the optimum pulping conditions for *P. bambusoides* were found to be screen yield 48.1%; reject ratio, 0.53%; Kappa no. 24.1%; viscocity 1210Ml/g; breaking length , 6.05km; burst index, 5.08kPam^2/g; tearing index 4.99mNm^2/g and brightness 20.35% . In a review on the papermaking process from bamboo, Akif and Nor (2021) suggested that kraft pulping with 18% active alkali produced the pulp with optimum values of burst of 5.60KN^m/$_g$, tensile 5.7.63(Nm/g)/10 which indicated that bamboo fibre can replace wood fibre in papermaking. Hidayati *et. al.* (2019) studied the effect of the ratio of acetic acid: formic acid on chemical properties of pulp from bamboo. The result indicated that increases in the ratio of formic acid are able to degrade cellulose, hemicellulose and lignin content and decrease pulp yield. The optimal ratio was reported as (:10. This pulping condition was observed to pulp with the following properties; Cellulose 66.98%, hemicellulose 16.83% and lignin, 3.5%. The pulp yield was reported as 42.27%.

The studies in literature indicated that bamboo is a good fibrous for pulp and paper production. Studies have also shown that various types of paper can be produced depending on the pulping processes adopted and the pulping conditions they are subjected to. Presently mills pulping bamboo abound in Asia and the Chinese Government is planning the establishment of more bamboo mills (Zhang, 2019). It behooves on countries with little wood resources and adequate bamboo resources to promote the development of virile pulp and paper mills in order to save foreign exchange on pulp and paper importation. The beauty of bamboo pulping is that it can be done on small, medium and large scales depending on availability of bamboo, investible funds and level of technological development of individual countries.

Pulping of mixture of bamboo and hardwoods

Various studies have been conducted on the possibility of pulping bamboo alone or in mixture with other bamboo species and or hardwoods. The cooking of different species (*M. smithii* and *B. vulgaris*) separately and as mixture and the papers made from both the pulps were described by Istas and Raekelboom (1960). For the production of unbleached pulps from a mixture of bamboo and mixed hardwoods, the minimum proportion of bamboo required is 50 per cent for good strength properties (Guha *et al*. 1966). Pilot scale trial production of bleached pulps from a mixture of 50:50 proportion of bamboo and mixed hardwoods at the Bengal Paper Mill, Raniganj, India was carried out under different conditions of sulphate pulping and bleaching. The ideal condition for the sulphate cooking is to use a sulphidity of 25 per cent with total chemicals of 15.5 per cent Na_2O at 170 0C for 2 hours. A pulp yield of 52 per cent can be achieved with permanganate number 18.8. Good breaking length (5310 m), burst factor (39.4), tear factor (120) and folding endurance (double folds of 240) can be expected. Studies on sulphate pulping of bamboo and mixed hardwoods showed that satisfactory high- and low brightness pulps and semi-bleached pulps could be obtained from a 50:50 mixture of bamboo and mixed hardwoods (Singh *et al* 1968). Bhargava *et al*. (1969) studied the effect of impregnation temperature and alkali concentration on the cooking of mixture of bamboo and mixed hardwoods. For a mixture of 60 per cent *Dendrocalamus strictus* and the remaining portion with hardwood, *Boswellia serrata*, the optimum unbleached pulp yield from chips cooked with 18.5-20 per cent active alkali was obtained at an impregnation temperature of 125^{0}C. With higher alkali concentration, a lower impregnation temperature can be used, but the total yield of unbleached pulp will be reduced. Generally, bamboos and hardwoods have different cooking characteristics. Thus, ideally, it is better to cook separately and then blend the pulps together. Bamboo and a hardwood, *Boswellia serrate,* although grown under the same climatic and soil conditions, had different cooking characteristics; while a better grade pulp with less chemical consumption was produced from bamboo by the 2-stage temperature treatment method, it took a 4- stage impregnation method for *B. serrata*. It was therefore observed that bamboo and *B. serrata* should be cooked separately. However, as the total bleach demand of the two pulps produced by the same method of cooking to the same kappa number level is very similar, pulps can be mixed together and bleached (Mishra and Rao 1969). In most cases for optimum pulp yield and of paper properties mills should carry out preliminary investigations on the of bamboo alone and co pulping with hadwoods . This is very important as the density, lignin and the extractive contents of hardwood vary consicerably. Primary investigations will enable the mills to identify the poosibily of cooking bamboo alone or pulping it together with different types of hardwood for optimum pulp and paper propertiesand yiels. In Nigeria in the 1960's to 1970's when bamboo and mixed hardwood were used to produce paperdifferent parameters were used for bamboo and hardwoods as some hardwoods used to deposit pitch on process equipment due to their high extractive contents.

Desilification of high silica content in black liquor

A number of authors have reported extensively the problems of desilification of bamboo pulping black liquor which usually contains silica in the range of 5-8 g/l as SiO_2. The high silica content leads to the formation of soluble silicates during pulping which causes troubles at the chemical recovery stage. The review by

Dhamodaran et al (2003) provided insight into the work of various authors in this regard. According to Tsuji and Ono (1966), the addition of calcium oxide to the black liquor is effective in reducing the silica content from 5.0-7.2 g/l to 1.3-1.8 g/l, and the precipitated calcium silicate is easily removed by filtration without reducing the amount of organic matter and sodium. Desilicification of high silica containing kraft black liquor is achieved by using various reagents such as aluminium sulphate and magnesium sulphate, carbon dioxide (Isono and Ono 1967; 1968) and kraft green liquor by aluminium sulphate (Isono and Ono 1968). Kulkarni *et al*. (1984) made an attempt for desilication by the method of lowering the pH of black liquor by carbonation. It was found that temperature and pH were the two important parameters that needed to be optimised for the selective precipitation of silica. The pH range for silica precipitation was largely influenced by the temperature during carbonation. Also it was found that at all temperatures and pH levels there was a co-precipitation of lignin. Treatment of sludge with calcium oxide or aluminium hydroxide at 80 ^{0}C helps in re-dissolution of co-precipitated lignin without dissolving silica portion. The carbonised black liquor can be filtered easily on 600 mesh nylon cloth under reduced pressure of around 0.3 kg/cm2. Sathyanarayana *et al*. (1992) made adaptations to black liquor evaporators so that a mixture of bamboo and hardwood pulp (at a ratio of 70:30) could be processed as effectively as bamboo alone. The viscosity of black liquors from bamboo alone and bamboo with mixed hardwoods in different proportions can be reduced with increase in initial residual alkali of the black liquor (Khare *et al*. 1984). This will help in reducing the clogging of the evaporated tubes and better performance at the recovery levelIn a recent study, Runge and Paul (2015) compared the effect f the dermis layerremoval and alkali extraction on Phyllostachys edulis before being subjected to kraft cooking. The pulp were then bleached with $OD_O(EP)D_1$ sequence. The results showed that 80% of silica could be removed from bamboo through a combination of dermal mechanical treatment and caustic extraction of the chips. Caustic chip extraction removed a significant portion of the hemicellulose materials which in turn lowere pulp yiels but have minimal effect on pulp properties.

Types of paper produce able from bamboo

Experiments conducted at the Forest Research Institute, Dehra Dun have established the suitability of bamboo as a material for the manufacture of kraft paper and have led to the pioneering of the industry in India (Bhargava and Singh 1942). The bamboo pulp from *Dendrocalamus strictus* combined with different proportions of mixed hardwood pulps has satisfactory properties for the manufacture of writing and printing paper, wrapping paper and 3- layer board (Guha *et al*. 1980). Newsprint was produced from the bamboo *Phyllostachys bambusoides* (Nafziger *et al*. 1961). *Dendrocalamus strictus* was reported to be suitable for the production of white papers (Guha and Pant 1961). *Phyllostachys bambusoides* is suitable for the production of writing and printing papers (Guha and Pant 1966). Ringal (*Arundinaria* spp.) is reported to be suitable for the production of chemical pulps by the sulphite process for writing and printing papers (Guha *et al*. 1966). Good quality bond, air-mail bond, onion skin, offset book, kraft wrapping and bag papers can be produced from the sulphate pulp of *Bambusa blumeana* (Escolano *et al*. 1964). *Bambusa vulgaris* was reported to be suitable for bag and wrapping papers with excellent tearing but poor bursting strength properties (Escolano and Semana 1970). The folding and tensile strength of both the pulp and paper are within the range of imported pulps/papers. Guha *et al*. (1970) reported that Braille printing paper can be successfully produced from Indian bamboos. Jati bamboo (*Bambusa tulda*) was reported to be unsuitable for manufacture of wrapping, writing and printing papers (Bhola 1976). *Oxytenanthera ritcheyi* was reported to be a suitable raw material for the production of wrapping, writing and printing paper (Bhandari 1981).

6. Recommendations and Conclusion

A lot of work have been and are still been done done on different aspects of bamboo pulping in several parts of the world. Reports by various authors indicated that bamboo can be pulped by various processes depending on the types of paper to be produced. In addition, bamboo can be pulped successfully with hardwoods to produce different types of paper. One of the major problems associated with bamboo pulp and papermaking is the issue of silica. Research and development has largely solved this problem. New technologies, such as silicon removing/silicon retention, have been developed to overcome the disadvantage of bamboo as pulping raw materials, as well as to improve the quality of bamboo pulp products (Xu *et al*. 2015, 2016). A good example of bamboo pulping and bamboo pulp products can be found at Chitianhua’s operation in Guizhou province of China, wherein the strong black liquor concentration reaches 70% and the alkali recovery rate is above 92%.

In countries that are lacking in wood, most especially, temperate softwood, deployment of bamboo for use in paper industry can alleviate the problems associated with long fibre pulp importation and the closure of pulp and paper mills as is the situation in Nigeria. This however requires adequate planning. Accompanied with the rapid economic development, China has become the largest paper production and consumption country in the world during the last decade. Simultaneously, a great change in the raw material structure of the pulp and paper industry has taken place in China. The proportion of non-wood fibers in the pulp and paper industry of China has exhibited a gradual decrease. However, due to shortage of wood resources, utilization of non-wood fibers remains important in China. The total production capacity of bamboo pulp in China reached 2,400,000 tons in 2017, and most of the bamboo pulps (about 80%) are for the production of household paper grades. It is worth noting that household paper grades prepared from unbleached bamboo pulp have become a welcomed product for customers and have achieved encouraging commercial success in China.

To promote utilization of bamboo for pulp production, local governments of China are providing support for bamboo plantation and improvement of transportation conditions. A special sub-committee of Bamboo Pulp Working Committee was established in 2016 under the China Paper Association to accelerate the development of bamboo pulping technology and enhance the collaboration between paper mills and research institutions. This approach is commendable and could be adopted by countries with significant bamboo resources.

According to Zhang (2019) several new bamboo pulp and paper projects have been planned in Sichuan Province of China, according to the 2017 Almanac of China Paper Industry. These include Yongfeng Paper's 2.0×10^5t/a integrated bamboo pulp and paper mill, Yibin Paper's 2.5×10^5t/a integrated bamboo pulp and paper mill, and the 1.5×10^5t/a integrated bamboo pulp and paper mill of Chinese Bamboo Paper Co., Ltd. As reported, the total production capacity of Chinese Bamboo Paper Co., Ltd will reach 1.0×10^6 t/a in next few years. These new bamboo pulping projects reflect China's strategy in utilizing its bamboo resources for the pulp and paper industry.

The strategy adopted in China can successfully be repeated in other bamboo endowed countries in Sub-Sahara Africa. However, the approach requires deep seated commitment of the government through provision of enabling environment and the private sector investors to fund bamboo pulp and papermaking projects in these countries.

References

Bhandari, K.S. 1981. Kraft pulping of Oxytenanthera ritcheyi. Indian Forester 107(7): 454-458.

Bhargava, K.S; Sharma, M.C; Maheshwari, D.K. 1969. The effect of impregnation temperature and alkali concentration on cooking of mixture of bamboo and mixed hardwoods. Indian Pulp and Paper 24(5): 257-258.

Bhargava, M.P; Chattar Singh. 1942. Manufacture of newsprint, cheap papers and boards. Indian Forest Bulletin 108.

Bhat, R.V; Viramani, K.C. 1957. Indian Forest Leaflet No. 123. FRI & Colleges, Dehradun.

Bhola, P.P. 1976. Pulping studies of hill jati bamboo (Bambusa tulda) from Cachar Hills. Indian Forester 102(4): 242-246.

Bhowmick, K; Akhtaruzzaman, A.F.M; Mian, A.J. 1992. Economic benefits of soda and kraft anthraquinone pulping of muli bamboo (Melocanna baccifera). Bangladesh Journal of Forest Science 21(1/2): 13-19.

Bhowmick, K; Mian, A.J; Akhteruzzaman, A.F.M. 1991. Anthraquinone as an aditive in kraft pulping of muli bamboo (Melocanna baccifera). Forpride News 3(5).

Chen, Z., Zhang, H., He, Z., Zhang, L., and Yue, X. (2019). "Bamboo as an emerging resource for worldwide pulping and papermaking," *BioRes.* 14(1), 3-5.

Eraldo Antonio Bonfatti Júnior1*, Elaine Cristina Lengowski, Alan Sulato de Andrade, Ivan Venson, Umberto Klock, Francides Gomes da Silva Júnior, Joaquim Carlos Gonçalez4, Graciela Inês Bolzon de Muñiz (2019): Bamboo kraft pulping . Adv. For. Sci., Cuiabá, v.6, n.4, p.791-796, 2019

Escolano, J.O; Semana, J.A. 1970. Bag and wrapping papers from Kayuan – Kiling (Bambusa vulgaris Schrad). The Philippine Lumberman 16(5): 36-40.

Goyal, P; Mishra, N.D. 1982. Vapour phase kraft pulping of bamboo (Dendrocalamus strictus). Indian Pulp and Paper 37(3).

Gremler, E.R; McGorovern, J.N. 1960. Low-power cold soda pulping. TAPPI Journal 43(8): 200A-205A.

Guha, S.R.D. 1961. Tour report of Dr. S.R.D. Guha to Culcutta and Luknow on February 1961. File on Bamboo, Doc. Section, Forest Research Institute and Colleges, Dehra Dun.

Guha, S.R.D; Sharma, Y.K. 1970. Chemical, semi-chemical and mechanical pulps from Casuarina equisetifolia. Indian Forester 96(11): 830-840.

Guha, S.R.D; Sharma, Y.K; Jain, R.C; Jadhav, A.G. 1966. Chemical pulps for writing and printing papers from ringal (Arundinaria spp.). Indian Forester 92(10): 634-636.

Guha, S.R.D; Singh, M.M; Bhola, P.P. 1975. Laboratory trials with Eucalyptus hybrid wood, fresh and after storage for newsprint. Indian Forester 101(8): 476-483.

Guha, S.R.D; Singh, M.M; Karira, B.G; Nair, V.K.S. 1980. Laboratory experiments on Andhra Pradesh hardwoods on behalf of Bhadrachalam Paper Boards Ltd. Indian Forester 106(7): 490-495.

Ilhan DENiZ, Onur Tolga OKAN, Bedri SERDAR, Halil İbrahim ŞAHiN (2017): Kraft and modified kraft pulping of bamboo (Phyllostachys bambusoides). Drewno 2017, Vol. 60, No. 200 DOI: 10.12841/wood.1644-3985.224.05

Islam, S; Bist, V; Chand, S; Pant, R. 1989. Hypochlorite bleaching of bamboo cold-soda high yield pulping for newsprint furnishes. Paper presented in the IPPTA Silver Jubilee International Seminar & Workshop on Appropriate Technology for Pulp and Paper Manufacture in Developing Countries, IPPTA, New Delhi: 12p.

Isono, Z; Ono, K. 1967. Desilicification of high silica containing kraft liquors. Part I.Desilicification of black liquor by carbon dioxide treatment. Journal of Agricultural and Chemical Society of Japan 41: 220-225.

Isono, Z; Ono, K. 1968. Desilicification of kraft green liquor by aluminium sulphate. Part II. Journal of Agricultural and Chemical Society of Japan 42: 18-23.

Istas, J.R; Raekaelboom, E.L. 1960. Paper making from a mixture of M. smithii and B. vulgaris. Bulletin of Agriculture. Congo Belge 51(2): 393-402.

Kadarisman, D; Silitonga, T. 1974. Sulphate pulping of bamboo. Bulletin Penelitan Tek Hasil Pertanian 40: 14-17.

Karnik, M.G. 1956. Varieties of paper. Indian Forester 82(1): 203-205.

Karnik, M.G; Sen, D.L. 1958. Journal of Scientific and Industrial Research (India) 7(8): p35.

Khare, A; Joshi, R.C; Bhargava, G.G; Singh, M.M. 1984. Behaviour of mill bamboo, bamboo + mixed hard woods (70: 30) percent, bamboo + mixed hardwoods (50: 50)

Kulkarni, A.G; Kolambe, S.L; Mathur, R.M; Pant, R. 1984. Studies on desilication of bamboo kraft black liquor. IPPTA 21(1): 37-44.

Maheshwari, S; Maheswari, O.N; Bajaj, V.D. 1988. Efficient management of bamboo storage to reduce cost of paper production. IPPTA 25(2): 1-7.

Mazzei, F.M; Rediko, B.V.P. 1967. Pulp for paper making from bamboo. Publicacao,

Mera, F. A. T., and Xu, C. (2014). "Plantation management and bamboo resource economics in China," *Revista Ciencia Y Tecnología* 7(1), 1-12.

Mishra, N.D; Kothari, M.B. 1969. A case study of bamboo fibre stock flow over a

Monsalud, M.R. 1964. Pulp and paper evaluvation of Philippine species. Annual Report 1963-64. Philippine Forest Products Research Institute.

Mukherjea, V.N; Guha, S.R.D. 1971. Production and studies of cellulosmace from bamboo (Dendrocalamus strictus). Indian Pulp and Paper 25(9/12): 535-541.

Nafziger, T.R; Clark, T.F; Wolff, I.A. 1960. Dissolving pulps from domestic timber bamboo, Phyllostachys bambusoides. TAPPI Journal 43(6): 591-596.

Nafziger, T.R; Clark, T.F; Wolff, I.A. 1961. Newsprint from domestic timber bamboo, Phyllostachys bambusoides. TAPPI Journal 47(7): 472-475.

Nazak, R.G; Handigol, M.P.H; Deb, V.K; Jaspal, N.S. 1979. AQ as an aditive in kraft pulping of bamboo (Dendrocalamus strictus). Indian Pulp and Paper 33(5): p17.

Nepenin, N; Bang, D.S. 1969. Obtaining kraft pulp from Vietnam bamboo. Cellulose Chemistry and Technology 3(6): 681-700.

Nicholas, P.M; Navarro, J.R. 1964. Standard cold soda pulping evaluation of Philippine woods and bamboos. TAPPI Journal 47(2): 98-105.

Ogunwusi, A.A. (2014a). Prospects for Increasing Pulp and Paper Capacities In Nigeria. 126pp. Published by Toyab Multilinks Investment Nigeria Ltd.

Ogunwusi, A.A. (2014b). Unlocking the Potential of Bamboo in Nigeria. 203pp. Published by Toyab Multilinks Investment Nigeria Ltd.

Ogunwusi, A.A. and Onwualu, A.P. (2013). Prospects for Multi-functional utilisation of bamboo in Nigeria. *Chemistry and Materials Researc*

Oye, R; Mizuno, T. 1970. Studies on bamboo dissolving pulp, reactivity of bamboo pulp for viscose. Journal of Japan Wood Research Society 16(2): 92-96.

percent and mixed-hardwoods kraft black liquor on evaporation and addition of alkali. IPPTcarrA 21(3): 29-36.

Raitt, W. 1911. Suitability of various woods, bamboos and grasses for paper making. Indian Forester 37(7): 389-390.

Raitt, W. 1912. Report on the investigation of bamboo as material for production of paper pulp. Indian Forest Records 3(3): 26p.

Rao, V.G; Murthy, N.V.S.R; Annam Raju, P.V; Sharma, G.S.R.P. 1983. Effect of pulp Sproull, R.C. 1955. TAPPI Journal 38: 593.

Sanyal, A.K; Devgan, R.C. 1964. Use of elemental sulphur in soda cooking of bamboo (Dendrocalamus strictus). Indian Pulp and Paper 18(9): 521-523.

Satyanarayana, G; Vaikuntam, K; Raghuveer, S. 1992. Improved performances of evaporators and chemical recovery boiler with the increased utilisation of hard woods at ITC Bhadrachalam Paperboards Limited. IPPTA 4(3): 121-122.

Sharma, A. K., Dutt, D., Upadhyaya, J. S., and Roy, T. K. (2011). "Anatomical, morphological, and chemical characterization of *Bambusa tulda*, *Dendrocalamus hamiltonii*, *Bambusa balcooa*, *Malocana baccifera*, *Bambusa arundinacea* and *Eucalyptus tereticornis*," *BioResources* 6(4), 5062-5073. DOI: 10.15376/biores.6.4.5062-5073

Singh, S.V; Bhandari, S.S; Singh, S.P. 1989. Organosolve pulping of Dendrocalamus strictus and Eucalyptus tereticornis with aquous ethanol. Paper presented in the IPPTA Silver Jubilee International Seminar and Workshop on Appropriate Technologies for Pulp and Paper Manufacture in Developing Countries. 1989, New Delhi.

Singh, S.V; Guha, S.R.D. 1975. Kinetics of alkaline pulping of Bamboo. Indian Pulp and Paper 30(3): 15-25.

Tissot, M. 1970. Bamboo as raw material for the Indian paper industry. Bios. For. Trop. 129: 21-45.

Tsuji, H; Isono, Z; Ono, K. 1965. Studies on the dissolving bamboo pulp. Bulletin of the University of Osaka Prefecture, Sakai, 16B(January): 89-104.

Tsuji, H; Ono, K. 1966. Studies on the silica removal by calcium oxide addition from black liquor of bamboo sulphate pulping. Bulletin, University of Osaka Prefecture, Osaka 18: 37-46.

Ujiie, M; Matsumoto, A. 1967. Studies on semi-kraft pulps from Sasa senanensis. Part I. Selection of the cooking conditions and comparison with Birch and Larch semi-kraft pulps. Research Bulletin of Experimental Forestry,

Hokkaido University, Japan 25(1): 287-321.

Wei, J., Du, C., Liu, H., Chen, Y., Yu, H., and Zhou, Z. (2016). "Preparation and characterization of aldehyde-functionalized cellulosic fibers through periodate oxidization of bamboo pulp," *BioResources* 11(4), 8386-8395. DOI: 10. 15376/ biores.11.4.8386-8395

Wu, Y. (2016). "Acceleration of bamboo forest base construction for bamboo pulp and development of bamboo, pulping and papermaking," *Paper and Papermaking* 35(5), 48-50. DOI: 10.13472/j.ppm.2016.05.012

Xu, Y., Sun, H., Li, X., Zhang, D., and Tian, Y. (2015). "Method of black liquor combustion to remove silicon from wheat straw pulping," *BioResources* 10(2), 1988-1997. DOI: 10.15376/biores.10.2.1988-1997

Xu, Y., Zhang, W., Sun, H., Yue, X., and Zhang, D. (2016). "Study on the dynamic viscoelasticity of bamboo kraft black liquor," *BioResources* 11(1), 2655-2664. DOI: 10.15376/biores.11.1.2655-2664